Institutional complementarities: The origins of experimentation in China’s plug-in electric vehicle industry

John P. Helveston⁎, Yanmin Wang⁎, Valerie J. Karplus, Erica R.H. Fuchs

Abstract

A vast literature on technology transitions within industries suggests that early phases of new technologies are marked by periods of intense experimentation, but we know little about the conditions under which these periods emerge. We apply inductive, grounded theory-building techniques to examine what prompts firms to experiment across one emerging technology platform—plug-in electric vehicles (PEVs)—in China. Triangulating annual vehicle make and model sales data from 2003 to 2016 (plus monthly data from 2010 to 2016); 112 English and Mandarin archival documents from industry, academic, and news outlets; and 51 semi-structured interviews with industry, government, and academic stakeholders, we develop four in-depth case studies. We find that in contrast to the innovation trajectories of multinational and Chinese arms of joint venture (JV) firms, independent domestic Chinese firms (those with no history of international JV partnerships) are undertaking significant experimentation across multiple levels—infrastructure, core system, subsystem, and component—of the emerging PEV technology platform. We propose the concept of “institutional complementarities” to describe how interactions among institutions—here the national JV regulation and local market support and subsidies—may have turned regional markets into protected laboratories, extending the incubation periods for independent domestic firm experimentation. While this diverse experimentation may be an important antecedent of technology transition, consolidation induced by national policy standardization or competitive pressure may be required for PEV innovations to scale beyond their early, protected regional markets.

1. Introduction

A vast literature has attempted to understand the factors necessary to enable and encourage technology transitions within industries. Literature on industry lifecycles (e.g. Agrawal and Gort, 1996; Gort and Klepper, 1982; Klepper, 1996; Suarez and Utterback, 1995; Utterback and Abernathy, 1975) as well as literature on industry ecosystems (Adner, 2006, 2017; Adner and Kapoor, 2010, 2016; Christensen, 1992b; Christensen and Rosenbloom, 1995; Henderson and Clark, 1990; Kapoor and Purr, 2015) suggests that early phases of new industries are marked by periods of intense experimentation and diverse entry by many firms, but less is understood about the origins of these periods of experimentation, and in particular how they are shaped by institutional forces. In this study, we advance this line of inquiry by probing the institutional antecedents of diverse experimentation by independent domestic Chinese firms across multiple levels of one emerging technology platform: the plug-in electric vehicle (PEV).

We focus our inquiry on explaining an empirical puzzle: although multinational automakers dominate China’s conventional vehicle market through joint venture (JV) firms and hold majority market shares in the U.S. and European PEV markets, multinational automakers are virtually absent from China’s PEV market, focusing instead on selling mature, incumbent conventional vehicle technologies. Meanwhile, independent domestic Chinese firms—those with no historic joint venture (JV) partnerships—have struggled to gain market share in China’s conventional vehicle market but are dominating...
China’s PEV market, experimenting across a wide variety of product and business model innovations. Any explanation for the emergence of experimentation across multiple levels of the PEV technology platform in China will need to address not only the drivers of experimentation among independent domestic firms, but also the near absence of PEV entry (let alone experimentation) among incumbent JV firms and the limited entry by Chinese partners of those JV firms.

In this study, we use the term “technology platform” to refer to a focal technology around which an interdependent set of complement providers and organizational structures exist. Prior literature has used the terms “platform” and “ecosystem” in similar ways. Gawer and Cusumano (2002) refer to a “platform” as a focal technology upon which a network of other actors innovate. Adner (2017) likewise refers to an “ecosystem-as-structure” concept, defined as the various industry partners that align to bring a focal value proposition to market. Different technology platforms may co-exist within one industry, and some complements may be shared; for example, while both internal combustion engine vehicles and electric vehicles share road infrastructure, they form two different technology platforms within the automobile industry.

Our research triangulates annual vehicle make and model sales data for 2003–2016 (plus monthly data for the most recent six years); 112 English and Mandarin archival documents from industry, academic, and news outlets; and 51 semi-structured interviews across industry, government, and academic stakeholders. Applying inductive, grounded theory-building techniques (Eisenhardt, 1989; Glaser and Strauss, 1967), our findings suggest that China’s national-level regulation requiring foreign firms to form JVs—aimed at facilitating technology transfer from foreign to domestic firms in a mature industry—has, perhaps unintentionally, resulted in a protected PEV market within which independent domestic firms have thrived. These results are surprising and offer a new perspective on prior work that finds the national JV regulations have largely failed to transfer technologies to Chinese partners and may have even hindered domestic innovation in the conventional vehicle industry (Brandt and Thun, 2010; Howell, 2018; Huang, 2003; Lazonick and Li, 2012; Nam, 2011). We also show evidence that local policy support for firms, in particular grants for technology development and subsidies to foster local market entry by local independent domestic firms, has transformed local markets into “laboratories” for diverse experimentation across multiple levels of the PEV technology platform.

We use the term “experimentation” in the context of the product cycle literature (e.g. Abernathy and Utterback, 1978) where the early phase of a new industry is marked by high levels of entry with diverse technologies and business models and no clear dominant design. In this study, we observe not only experimentation in the focal product (the PEV) but also across multiple levels of the PEV technology platform. We unpack this platform-wide experimentation through four in-depth case studies of independent domestic Chinese firms: Chery New Energy Vehicles, Haike Technologies, Jiayuan Electric Vehicles, and Kandi Technologies. Chery is a traditional automaker that is designing, manufacturing, and selling both conventional gasoline and PEVs; Haike is an automotive transmission start up company developing a low-cost flywheel hybrid transmission for PEVs; Jiayuan is developing low-cost, low-speed electric vehicles; and Kandi is developing PEVs for its car sharing business. The firms face different regulatory constraints, target different market segments, and have unique histories that have led to different capabilities and distinct areas of experimentation across the PEV technology platform, including infrastructure (Kandi), core system (Chery, Jiayuan, and Kandi), subsystem (Haike), and component (Haike and Jiayuan) levels.

We use evidence from the divergent development paths of these case studies to propose the concept of “institutional complementarities” as a mediator of the strength of incentives for firms to experiment as well as the range of experimentation firms engage in across different levels of an emerging technology platform. We further propose that such platform-wide experimentation may be important in enabling a new industry to emerge, consolidation enabled by policy or competitive pressure may be required for PEV innovations to scale beyond their early, protected regional markets. That is, the same diversity of localized conditions that may be leading to diverse experimentation across the PEV technology platform may also impede the emergence of stronger regional or national market players in the domestic and global PEV industry in the medium to long term. We hypothesize that greater national harmonization of PEV regulations, technology standards, and R&D support will be needed to enable the continued development of the technology platform at scale.

2. Literature

2.1. Platform-wide experimentation and technological change

A vast body of literature has investigated the evolution of industries and the dynamics of technological change. While the nature of these studies varies, a common observation is that industries follow a cycle: early phases are marked by intense experimentation and diverse entry followed by a “shake out” period where a dominant design emerges and the number of firms as well as the rate and diversity of product innovations decline as firms shift their focus towards process innovations (Abernathy and Utterback, 1978; Agarwal and Gort, 1996; Gort and Klepper, 1982; Klepper, 1996; Suarez and Utterback, 1995; Utterback and Suárez, 1993). Our study contributes new evidence of how overlapping institutions may facilitate and shape the early experimental phase of not just a new product but a new technology platform—a focal technology around which an interdependent set of complement providers and organizational structures exist. In this stage, no dominant design has emerged and the future success of different technologies and business models is uncertain.

Although the product cycle pattern has been documented across a number of industries (Klepper, 1996; Suarez and Utterback, 1995; Utterback and Suárez, 1993), prior literature has often focused on the evolution of specific products (e.g. automobiles, televisions, and disc drives) while omitting the broader set of complementary products, services, and infrastructure (e.g. refueling stations, broadcast standards, and the USB standard) that necessarily evolved along with those products in order for the industries to emerge. Recent work on technological change has emphasized the importance of considering the emergence challenges of focal firms (Henderson and Clark, 1990; Tushman and Anderson, 1986) along with the broader “ecosystem” of complement providers within which those firms are embedded. This research emphasizes that the successful diffusion of a focal firm’s innovation often depends on the performance of other innovations that are complementary (and often external) to that firm (Adner, 2006, 2017; Adner and Kapoor, 2010). For example, Constant (1980) shows that the substitution of piston aircraft engines for turbojet technology occurred not by a smooth substitution of one technology to another but rather through a series asynchronous, discontinuous performance improvements across a variety of interdependent complement providers from a range of industries (Constant, 1980). In this example, the piston engine and turbojet engine represent different “technology platforms” within the aircraft industry for which there may be overlapping and interconnected complement providers and organizational structures.

Past research highlights how interdependencies between technologies and ecosystems may affect the pace of substitution from an incumbent to emerging technology ecosystem (Adner and Kapoor, 2016). In particular, historical cases of ecosystem “bottlenecks” draw attention to how interdependencies may affect the timing of when certain technologies or industries emerge. For example, while high-definition television sets were arguably ready for mass market consumption since the early 1990s, their adoption was likely delayed by a lack of complementary innovations, such as high definition broadcasting standards and studio production equipment (Adner, 2006). In the evolution of the
American machine tool industry, interdependencies between different machine tools created “technological imbalances” that may have delayed the development of other tools (Rosenberg, 1976); and in the evolution of the electric power system, constraints in transmission technologies for direct current power likely contributed to the dominance of alternating over direct current power systems (Hughes, 1983).

In this study, we examine the emerging PEV technology platform. Like other technology platforms that have been studied, performance improvements or structural changes to subsystems can affect both the performance and performance requirements of other subsystems. For example, an improvement in battery energy density can reduce the vehicle weight and battery capacity needed to achieve a desired driving range and acceleration time; in contrast, the use of a different business model, such as car sharing, might reduce the battery energy density requirements since shared vehicles can operate with shorter driving ranges, enabling the opportunity to use less-advanced (and perhaps also less expensive) battery cells. In addition, interdependencies across different components or subsystems across the technology platform may lead to ecosystem “bottlenecks.” For example, the ability to rapidly charge a PEV battery may depend on both charging infrastructure and battery innovations, which may evolve at different paces. Fig. 1 illustrates several examples of interdependencies across the PEV technology platform.

While theories from the product cycle, dominant design, and ecosystems literatures point to the importance of early experimentation in bringing about technological change, less is known about what brings about or shapes the emergence of a new technology platform. Our study provides novel evidence of how overlapping institutions can encourage experimentation across the suite of complementary innovations that may be required for a new technology platform to emerge. Our findings thus suggest a new mechanism of interest to the product lifecycle (or industry evolution) and platform innovation literatures.

2.2. Institutional design and technological change

Beyond offering an institutional mechanism to explain experimentation, our study explicitly considers the appropriate role of government intervention in supporting desired technology transitions. There is an extensive literature on how institutions and policy may be able to influence the pace and direction of technological change in both developed and developing countries (Amsden, 2001; Block, 2008; Breznitz, 2007; Fuchs, 2010; Lerner and Stern, 2012; National Research Council, 1999; NBER, 1962; Nelson, 1993; Victor and Nelson, 2002). Nelson (1993) argues that institutional actors (e.g. firms, research labs, universities, government labs) can shape the nonlinear process of technological change, ultimately affecting the competitiveness of countries’ national innovation systems. For example, research has suggested that institutional factors related to Japan’s national innovation system (rather than the failure of individual firms to innovate) were responsible for the extended economic downturn in Japan during the late 1990s (Victor and Nelson, 2002). Research on directed technological change has shown that policy instruments such as subsidies for R&D and carbon taxes can lead to faster adoption of CO2-reducing technologies in the energy industry (Acemoglu et al., 2012; Veugelers, 2012). Breznitz (2007) argues that state institutions were crucial in facilitating the aggregation of otherwise fragmented private sectors in Israel, Taiwan, and Ireland in order to develop innovation-based export sectors.

Research on China has emphasized how Chinese policy can support distinct technology directions within China versus global markets, and how the combination of national and local institutions can often have unintended implications for technological change. In the case of the technological transition from second- to third-generation cellular networks, Zhang (2016) argues that the direction of technological change was driven by meso-level institutional factors that prioritized support for the Chinese-developed TD-SCDMA technical standard, even though the majority of the global telecommunications industry adopted a different standard (Zhang, 2016). Likewise, it has been well-documented how “high-technology zones” established by the central government for advancing technological R&D have been repurposed by local governments as capital-intensive, export-oriented manufacturing facilities to achieve faster economic growth at the expense of technology development (Heilmann et al., 2013). In the case of wind turbine and solar panel manufacturers in the energy industry, the combination of China’s national innovation system, which provided entrepreneurial firms access to global production networks through licensing and collaborations with foreign partners, and local innovation systems, which provided support for more traditional manufacturing activities through incentives such as tax breaks, low-cost land, and preferential loans, may have ultimately led to the unanticipated emergence of rapid, cost-effective manufacturing techniques (Nahm, 2014). Here, the development of specialized, knowledge-intensive capabilities in technology scale-up and commercialization, or “innovative manufacturing,” may have increased the adoption rates of wind and solar technologies (Nahm and Steinfield, 2014). Breznitz and Murphy (2011) suggest that it is precisely these innovative capabilities in product commercialization that may be the key to sustainable economic growth for China’s future.

Our findings on the antecedents of platform-wide experimentation have implications for the literature on institutional design and policy. First, our findings reveal a role for “institutional complementarities” in
enabling a technology platform’s emergence, influencing both its nature and variety; importantly, it calls for broadening the boundaries of evaluations that focus on single policies. Second, our findings reinforce prior studies’ conclusions on the potentially potent non-target effects of institutions on technological change. Third, our findings illustrate how institutions may enable a technology’s emergence in an early stage but may constrain its progress in a later stage, necessitating an evolution of policy tailored to various stages of transition.

3. Background

3.1. The joint venture regulation and the rise of China’s automotive industry

Over the last decade, China has rapidly grown to become the largest passenger car market in the world, with annual sales growing from approximately 4 million in 2005 to nearly 20 million in 2015 (OICA, 2015). One of the most influential institutions that has shaped the rapid development of China’s automotive industry is the Joint Venture (JV) regulation, which requires foreign automakers to join with a domestic Chinese partner firm (often large state-owned enterprises) to create a distinct JV firm in order to manufacture and sell vehicles in China. By limiting foreign firm ownership of the JV to less than 50%, the objective was for the JV to facilitate technology transfer from the foreign firms to the Chinese JV partner firms (Gallagher, 2006; Lu and Feng, 2005; Naughton, 2007). Since the establishment of the first JV firm (Beijing-Jeep) in 1984, JV firms have remained the dominant players in China’s automobile market.

Despite being rooted in the industrial policy strategy of 以市场换技术 (yì shìchāng huàn jìshù), or “trading the market for technology,” research suggests that the JV system did not have its intended effect. Rather than absorbing foreign technology and know-how, Chinese JV partner firms became dependent on their foreign partners’ technology and brands and failed to develop their own independent R&D capabilities (Brandt and Thun, 2010; Howell, 2018; Huang, 2003; Lazonick and Li, 2012; Nam, 2011). Nam (2011) uses a case study to illustrate how Chinese JV partner firms became engaged in a “passive” learning mode with their multinational partners, leaving their innovation capabilities less developed. Howell (2018) uses quantitative evidence to show that the JV regulation reduced Chinese JV partner firms’ investments in products that might compete with their JV’s products. Recent research suggests that the maturity of the traditional automobile industry and lack of technological uncertainty may have been a key factor limiting the leverage of the JV requirement in encouraging technology transfer from foreign to domestic firms (Prudhomme and Zhang, 2017; Prud’homme et al., 2018). Referring to JV firms’ dependence on multinational partners for technology and brands, former Minister of Machinery and Industry He Guangyuan said, “It’s like opium—once you’ve had it, you will get addicted forever” (Reuters, 2012).

For the purposes of this paper, we label domestic Chinese firms that have not historically developed under JV partnerships “independent” domestic firms. We intend this distinction to go beyond the legal associations of firm ownership to reflect the potentially path-dependent history of these firms. Notably, distinguishing some firms as “independent” with respect to the JV system does not imply that their technology developments are also independent of input or influence from outside the firm. As our case studies reveal, independent domestic firms can and do acquire know-how by working with international partners, albeit not through formal JV entities.

3.2. China’s policy push for plug-in electric vehicles

The central government recently identified 新能源车 (xīn néngyuán chē), or “new energy vehicles,” as a priority industry in its 2015 “Made in China 2025” industrial policy, which targets ten strategic industries deemed critical to China’s future economic competitiveness and growth (U.S. Chamber of Commerce, 2017). Here, the central government’s definition of “new energy vehicles” includes plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs)—collectively “plug-in vehicles” (PEVs)—as well as fuel cell vehicles (FCVs). We focus in this paper on PEVs. Today, China is the largest national market in the world for PEVs. In 2017, PEV sales in China accounted for nearly half (49%) of all PEVs sold in the world and were greater than the combined PEV sales in Europe and the U.S. (see Fig. 2).

Policy support for a domestic PEV industry has a history dating back to the inclusion of PEVs in China’s 863 national R&D program in the 1980s. Since then, support for PEVs has grown in strategic importance as a means to reduce oil consumption, greenhouse gas emissions, and air pollution from passenger cars as well as provide an opportunity for technological upgrading by Chinese automakers. With the global PEV industry still in its infancy, some Chinese policy makers hope that innovative Chinese firms can “leapfrog” to PEVs without having to develop frontier innovation capabilities in internal combustion engine technology (Howell et al., 2014).

From 1990–2010, various government bureaus have implemented policies to support China’s PEV industry. Starting in 1990, the 8th National Key Technology R&D Program supported small-scale PEV demonstration projects. In the late 1990s, the government began larger, state-sponsored R&D projects along with more localized demonstration projects. Under China’s 10th five-year plan (2001–2005), the Ministry of Science and Technology (MOST) established the Electric Vehicle Key Project under the 863 Program, providing $290 million for new energy vehicle development. By the 11th five-year plan (2006–2010), the total funding had grown to $1.5 billion through a multitude of policy experiments (Gong et al., 2012). These efforts culminated in the successful demonstration of 600 new energy vehicles in the 2008 Beijing Olympic Games (Xu and Su, 2016).

In 2009, the Ministry of Finance (MOF) and MOST jointly launched an expanded demonstration program called 十个世界（shí gè shìjiè）, or “Ten Cities, Thousands of Vehicles” (TCTV). The program deployed new energy vehicles in 25 select pilot cities, focusing on public fleet vehicles such as taxis and buses (MOF, 2009, 2010a,b). Through the pilot program, the central government offered vehicle purchase subsidies while leaving local governments responsible for funding supporting infrastructure such as charging stations. In 2010, the central government expanded subsidies to private consumers for the first time, and the NEV industry was listed as one of the seven national strategic emerging industries (Xu and Su, 2016). However, new energy vehicle deployment fell far below government targets (Gong et al., 2012), and rather than advancing a national new energy vehicle sector, evidence suggests many participating cities used the national funds to support local automotive firms (Zheng et al., 2012).

During the 12th five-year plan (2011–2015), the State Council released one of the most important planning documents directing the future of PEV development in China: 技能与新能源汽车产业发展规划
make, model, and trim. Since the CAAM automotive yearbooks are only published in print, we hand-copied the data into spreadsheets. We used a custom-built web scraper in Python to collect sales data from gasgoo.com to triangulate against the automotive yearbook sales. These data largely agree over their overlapping years (2010–2016) with only small variation between a few firms, none of which differ by an order of magnitude at the annual level. Aggregated sales totals by manufacturer and brand also match those reported by the China Passenger Car Association (Table 1).

4.2. Interviews

We conducted 51 semi-structured interviews totaling nearly 70 h between May 2014 and October 2016. Interviewees were contacted through a combination of a snowball technique (previous interviewees introduced future interviewees) and cold-calling different sources. Approximately half of the interviews (27/51) were with managers and engineers at our four focal case study firms; 10 of the interviews were with managers and engineers at JV firms, and 14 were with a variety of stakeholders in China’s PEV industry, including university researchers, non-profits, government experts, consultants, and reporters. Interviewees outside the four case study firms provided important perspectives (in particular from more senior managers at JV firms) from individuals with several decades of experience working in multiple automotive firms in China and abroad. Gaining insights from these interviewees provided alternative perspectives from which to better understand statements from the case study firm interviewees. These interviews also clarified the historical context of how China’s automotive market has evolved over time and the role policies have played in shaping the market today, in particular with respect to strategies of multinational firms operating within the JV system. Finally, interviews with JV firm managers and outside industry experts were used to cross-check the information from our interviews with the independent domestic case study firms.

4.3. Archival data

We collected additional archival materials (not including the sales data) on each case study firm. These documents included scholarly reports on the firms, such as previous case studies from non-academic English and academic and non-academic Chinese sources, press briefings about events in a firm’s history, investment reports, company presentation materials, magazine articles, and news reports. As the only publicly-traded firm among our cases, Kandi Technologies had many more available archival materials, including quarterly SEC filings from 2008 through 2016 and online investor reports. Table 2 below summarizes the full set of interviews and archival documents obtained. Table 4 in the Appendix provides a detailed list of the interviewees by organization and position, and Table 5 in the Appendix provides a detailed list of the archival documents.

5. Results

We present our results in two sections: First, we show evidence of how the national JV regulation has led to the dominance by independent domestic Chinese firms in China’s emerging PEV industry. Second, we unpack four case studies of independent domestic firms to illustrate the range of experimentation by these firms across the PEV technology platform, including at the infrastructure, core system, subsystem, and component levels.

5.1. Independent domestic firms are leading China’s PEV industry

Analysis of our interview, sales, and archival data revealed that the PEV industry in China is being led by one subset of automotive firms: independent domestic Chinese firms. Our evidence suggests that the
national JV regulation may be influencing this trend by creating disincentives for foreign automakers to bring PEV technologies to China. By licensing and selling relatively older traditional vehicle technologies from their home markets, foreign firms have been able to maintain high prices and make record profits through their JV firms, even after splitting profits with their Chinese partners. As one former JV firm manager said, “Selling gas cars makes money! The business case [for PEVs] is weak. Margins [for conventional vehicles] in the west are only 3–5%, but in China they’re around 10%!” Another senior engineering manager at a Chinese JV partner firm said, “The JV firms, they have their own ideas and views. Their views are to earn money…they have no industrial desire to get involved in EVs because their traditional cars are selling so well.”

In addition, foreign firms perceive bringing their most advanced conventional and PEV technologies to China (along with necessary global suppliers) at large scale as exposing themselves to unnecessary risk. Participation in a JV requires that foreign firms share intellectual property with their JV partner firms that could later become competitors. In addition, to receive subsidies, they would have to develop or source one of the three core drivetrain components (motor, battery, or control system) in China, but doing so is not a trivial matter. Given how new PEVs are to the world, most foreign OEMs have developed and sourced these core PEV components outside of China. For example, one manager from a multinational automotive firm said, “We do not have a single supplier in China that can make the bearings we require for our motors.” Focusing instead on established conventional vehicle product lines with established supply chains is a more conservative strategy that has resulted in high profitability and lower uncertainty.

Global vehicle sales data compared across the three largest conventional and PEV markets (China, Europe, and the U.S.) are consistent

Table 1
Summary of sales data collected.

<table>
<thead>
<tr>
<th>Years</th>
<th>Data type</th>
<th>Collection Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003–2016</td>
<td>Annual sales by make and model</td>
<td>Hand-curated from archives at Tsinghua University</td>
</tr>
<tr>
<td>2010–2016</td>
<td>Monthly sales by make, model, &amp; trim</td>
<td>Scraped using Python</td>
</tr>
</tbody>
</table>

Table 2
Summary of interviews and archival data.

<table>
<thead>
<tr>
<th>Category</th>
<th>Organization</th>
<th>Interviews</th>
<th>Archival Documents</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number of Unique Interviewees</td>
<td>Total Number of Interviews</td>
</tr>
<tr>
<td>Case Study Firms</td>
<td>Chery NEV</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Jiayuan EVs</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Haikou Technologies</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Kandi Technologies</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>JVs</td>
<td>JV Firm 1</td>
<td>4</td>
<td>5</td>
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<tr>
<td></td>
<td>JV Firm 2</td>
<td>1</td>
<td>1</td>
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<td></td>
<td>JV Firm 3</td>
<td>2</td>
<td>2</td>
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<tr>
<td></td>
<td>JV Firm 4</td>
<td>1</td>
<td>1</td>
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<tr>
<td></td>
<td>JV Firm 5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Other (secondary sources)</td>
<td>Universities</td>
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<td>4</td>
</tr>
<tr>
<td></td>
<td>Non-profits</td>
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</tr>
<tr>
<td></td>
<td>Government</td>
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</tr>
<tr>
<td></td>
<td>Consultants</td>
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</tr>
<tr>
<td>Total</td>
<td></td>
<td>45</td>
<td>51</td>
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*4 Interview 7.  
*5 Interview 30.  
*6 Interview 28.  
*7 Interviews 1, 2, 7, 9, 10, & 13.
Vehicle sales data within China are also consistent with this trend (see Fig. 4). While JV firms dominate conventional vehicle sales—largely through multinational brands—they are struggling to gain market share in China’s PEV market against competition from independent domestic Chinese firms. With nearly 260,000 PEV sales in 2016, independent domestic Chinese firms sold approximately one third of all PEVs sold worldwide. Although these firms only captured 18% of the conventional vehicle market in 2016, the lack of JV presence in PEVs has provided the opportunity for these same firms to capture 74% of the PEV market.

Interviews with multiple independent domestic firms revealed a wide range of experimentation across multiple levels of the PEV technology platform, from infrastructure and business model experimentation to core system, subsystem, and component levels. To examine the origins of this platform-wide experimentation in more detail, we explore four case study independent domestic firms.

5.2. Examples of platform-wide experimentation: four independent Chinese firm case studies

Our in-depth interviews unpack four examples of the different experimentation by independent Chinese firms across China’s emerging PEV technology platform: Chery New Energy Vehicles, Haike Technologies, Jiayuan Electric Vehicles, and Kandi Technologies. In focusing on these four firms, our intent is not to identify a representative or exhaustive set of all independent domestic firms or innovations but rather to illustrate how the experimentation by independent domestic firms is occurring across multiple levels of the PEV technology platform, including infrastructure (Kandi), core system (Chery, Jiayuan, and Kandi), subsystem (Haike), and component (Haike and Jiayuan) levels. The selection of these firms was emergent from the data collection process (George and Bennett, 2005; Piore, 1979)\(^\text{13}\). Two of these firms (Kandi and Chery) were the 5\(^{th}\) and 7\(^{th}\) top-selling PEV firms in 2016 with 5.4% and 4.9% market shares, respectively; for comparison, the average market share by any one firm was 4.3%. While Haike and Jiayuan are still in start-up phases, they provide important insights into experimentation happening in other areas of the technology platform, all of which may potentially be necessary to enable the introduction of PEVs. Comparing the histories of each firm, we find a combination of national and local institutions may be supporting these independent domestic firm experiments.

5.2.1. Chery new energy vehicles\(^\text{14}\): 脚踏实地 (Stepping on solid ground)

Chery New Energy Vehicles (hereafter referred to as Chery NEV) is an example of a firm experimenting at the core system level of the PEV technology platform. By re-designing a vehicle architecture from the ground up, Chery NEV was able to design a common vehicle platform that can be produced with either a conventional or battery electric powertrain along the same, integrated production line. This

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\(^{13}\) Our case selection approach differs slightly with other important case study traditions. For example, Eisenhardt recommends selecting cases prior to entering the field (Eisenhardt, 1989); in contrast, one might view our process as having more iterations between the field work and case selection process, allowing for cases to emerge before undertaking a basic characterization of experimentation across the PEV technology platform.

\(^{14}\) Official Name: 奇瑞新能源汽车技术有限公司 (Chery New Energy Automotive Technology Co., Ltd.)
architectural change has reduced the production cost of their BEV even with relatively low BEV production volumes since other shared components are still mass produced for the conventional version of the vehicle.

Chery NEV is a subsidiary of the larger automaker Chery Automobile, an independent domestic automaker owned by the local government of the city of Wuhu in Anhui province. Founded in 1997 as an automotive parts supplier, Chery has gradually expanded and become one of China’s largest independent domestic automakers with six domestic production plants and 15 complete knock down plants in developing nations around the world. From 2003 to 2011 annual sales grew from approximately 90,000 to 630,000 conventional vehicles, including exports.

Over the company’s 15-year history, Chery has transformed from a technology imitator to a technology integrator, with integrated design and production capabilities for both conventional and plug-in electric vehicles. Chery accumulated much of its technology as well as vehicle design and production capabilities by conducting joint R&D projects with multinational automotive suppliers and consultants and aggressively hiring experienced engineers and managers from multinational automakers. Rather than simply outsourcing design work to automotive suppliers, Chery used its relationships with global auto suppliers as conduits for absorbing technical skills and know-how. Describing a past joint R&D project, the assistant manager to the president said, “The most important thing is doing it...learning by doing is the path to doing it on your own.”

For example, Chery jointly developed its ACTECO engine line (its first engine brand with self-owned intellectual property rights) by working with the Austrian engine firm AVL. From 2002 to 2008, their collaboration evolved from one where AVL served as “master,” managing product development timelines and conducting R&D primarily in Austria, to “consultant,” where AVL supplied technical assistance while nearly all R&D was managed and conducted within Chery’s automotive R&D center in Wuhu. The collaboration produced three engine designs developed for 18 vehicle models. During that same period, Chery’s R&D force grew from approximately 500 engineers to nearly 3000.

Not all collaborations led to successes. Chery’s first hybrid vehicle was developed with British automotive consulting firm Ricardo from 2006 to 2008. Chery originally sent a small team of 20 engineers to train with Ricardo on a hybrid electric powertrain, but their lack of experience left the team dependent on foreign support, especially with integrating the battery management system. The former project director at Chery reflected on the collaboration using an analogy of a racing team where Chery was the “driver” and Ricardo was the “coach,” but the four “wheels” were four international suppliers providing the technology to make the system run. “Without these suppliers,” he said, “the ‘car’ wouldn’t have any ‘wheels’!” The project resulted in two hybrid technologies: an integrated starter generator and a belt-driven starter generator, which are reported to reduce fuel consumption by 22% and 7–10% compared to Chery’s conventional vehicles. Although the hybrid was showcased in the 2008 Beijing Olympics as the first (and only, at the time) produced by a Chinese automaker, it’s drive train was not as advanced as other fully integrated hybrid systems such as that in the Toyota Prius. In addition, payment to Ricardo and other international suppliers was expensive, and Chery’s engineers were unable to fully control the vehicle design without foreign support. While the project was ultimately abandoned after the Olympics, the original founder of Chery NEV described the experience as an important “stepping stone” towards developing their next project (the S18 BEV) on their own.

Chery has also acquired skills and know-how by hiring experienced technical experts and managers from multinational automakers. Many of Chery’s early engineers came from the R&D centers of large state-owned automakers with JV partnerships. Since the multinational half of JV firms conducted the majority of technical R&D, underutilized engineers at the Chinese partner half were eager to join Chery. Even Chery’s president and CEO, Tongyao Yin, was a 12-year veteran and star engineer at FAW as manager of the FAW-Volkswagen Jetta plant. Over 100 FAW workers left to join Chery to develop the A11 “Fengyun,” Chery’s first vehicle, a variant of the SEAT Toledo based on the VW Jetta. Much of the R&D work for the following three models released in 2003 was done by engineers from Dongfeng Motors, another large state-owned automaker that share a JV with Volkswagen.

Chery has also filled many management positions with 海龟 (hǎiguī), or “sea turtles,” a term used to describe experienced Chinese technical experts who left China in their youth to work abroad before returning to China later in life, bringing deep technical and managerial know how and often 20 or more years of experience. For example, Ming Xu, who worked for Visteon in Detroit, was hired in the early 2000s as director of Chery’s R&D center. Past research has suggested that these returnees have played an important role in the growth phase of Chinese firms (Kenney et al., 2013). Some of these sea turtles were also part of a national program called 千人计划 (qiānrén huá), which offers RMB 1 million ($140,000) to incentivize talented individuals to aid domestic Chinese firms in developing technical knowhow. A former senior engineer at Chery referred to these 海龟 as “secret weapons” as they are perceived as having been critical in deciding where to focus technical efforts and prioritizing which problems to solve in order to shorten timelines to the start of production.

Over time, Chery has applied its conventional vehicle design and production capabilities towards developing its PEV business, Chery NEV. In 2001, Chery NEV began its first PEV project after receiving a RMB 100,000 ($14,000) research grant from China’s 863 national R&D program. Chery managers and engineers (including the founder of Chery NEV’s R&D department) explained in interviews that they began exploring PEV research so early in its infancy to “capture the market opportunity” created by international automakers that were hesitating to develop PEVs for China and supported by national and local subsidies.

While integrating PEV components was the largest early technical challenge, a more fundamental challenge at the time was sourcing them given how few PEV component suppliers existed in China in the early 2000s. As a result, much of Chery NEV’s early R&D efforts were on developing components such as motors, controls, and batteries with emerging suppliers such as Tianjin Gateway, Wanxiang, and Shanghai Electric Drive—now all major suppliers in the industry. Reflecting on the PEV industry in the early 2000s, one of Chery NEV’s founders said,
“There were no shortcuts—we worked with partners, suppliers, and dealers to establish an entire ecosystem for making EVs.”

The early PEVs of that time were seen mostly as engineering prototypes and the first products of a series of innovation design stages.

Chery NEV’s business grew along with China’s national policies. In the mid 2000s, China entered a demonstration stage where special standards for PEVs, such as a maximum speed, crash safety, horse power, and range, were introduced nation-wide to improve production consistency even though they were lower than those for conventional vehicles. As products matured, tighter sets of standards were released and pilot programs such as “Ten Cities, Thousand Vehicles” which provided PEV subsidies to private buyers were implemented to increase domestic sales. Chery NEV designed its S15 BEV to meet these standards, which required the use of lithium ion batteries.

The S15 was the predecessor to their most recent BEV, the eQ. A major breakthrough and cost-saving measure for the design of the eQ was developing a common platform with the QQ5, one of Chery’s more popular conventional vehicles. Since the original BEV S15 was built on the same chassis as the conventional QQ, the floorboard had to be raised to fit in batteries, which significantly reduced passenger leg room. In addition, battery pack development took almost 3 years and required 8 different battery modules to fit into the chassis. After realizing these design flaws, Chery NEV co-developed a new platform with the larger Chery Auto platform division that uses a common chassis between the conventional QQ5 and BEV eQ, which today share over 90 different component modules and are both assembled on a single production line. The common platform helped reduce battery pack development time to 18 months and also enabled a more flexible battery module system allowing customized driving ranges. While high battery costs from two different Chinese suppliers still make the eQ more expensive than similarly sized conventional vehicles, current subsidies bring the price down to under RMB 80,000 (~$12,000) and even lower in some cities with the addition of local subsidies. For comparison, Chery’s conventional QQ5 sells for RMB 40,000–55,000 (~$6000–$8300). Since going on the market in 2014, Chery NEV has sold 30,000 eQ BEVs.

In summary, Chery NEV’s strategy responded to both national and local incentives to produce a highway-ready BEV to compete with conventional vehicles in lower-tier cities where prices may be more influential than brand. While most BEVs designed by foreign automakers are priced in higher segments, Chery focused its R&D on re-engineering its cars using advanced technology in favor of battery technology for energy storage. The primary concern was the ability to safely control the energy stored in the battery pack and motor. While Haike is focused on implementing their solution for BEVs, the system could also be used to improve efficiencies in traditional gasoline vehicles similar to existing hybrid electric powertrains such as that in the Toyota Prius—a larger market of nearly 2 million hybrid vehicle sales worldwide compared to 700 thousand PEVs in 2016.

Early applications of the flywheel hybrid technology were originally developed for large stationary energy storage used in accelerating and decelerating light rail systems. One of the earliest vehicle applications was the 1991 Chrysler Patriot, an early prototype hybrid race car. During the 1990s, concerns over safety ultimately led to the U.S. and British governments refusing to grant research funding on the technology in favor of battery technology for energy storage. The primary concern was the ability to safely control the energy stored in the flywheel that, as one of Haike’s engineers put it, is like “taming a wild animal.” The inability to secure R&D funding in England and the U.S. in the late 1990s and early 2000s was one of the motivations to consider commercializing the technology in China.

Nearly all development for vehicle applications of the technology has occurred by two firms in England and Haike in China. The two British firms have focused on the niche market of formula racing where flywheels have been strategically used for improving energy recovery and rapid acceleration. These systems typically use advanced carbon fiber flywheels that can spin up to 60,000 rotations per minute to maximize energy storage. Due to the small market size, customization requirements, and complex manufacturing processes associated with these systems, they are produced in low volumes. In contrast, Haike is developing their technology for mainstream commercial and industrial PEVs using a solid metal flywheel with a maximum speed of only 20,000 rotations per minute. Coupled with an electric motor for control, Haike’s system stores an adequate amount of energy but can be mass produced at a lower cost using established manufacturing processes.

Haike Technologies was co-founded by Dr. Frank Liao, a qianren and sea turtle with over 20 years of experience in automotive engineering in the U.S., and the technology’s patent holder from the U.K. As a consultant at Magna in 2005, Dr. Liao became interested in the technology through academic papers on the topic, and in 2006 he was awarded a patent on the system in the U.S. In 2009, he became the Chief Technology Officer at Beijing Automotive New Energy Vehicle with hopes of implementing the technology, but company leadership rejected his proposal. In 2012, Dr. Liao left Beijing to found Haike Technologies with the goal of commercializing the technology and becoming a Tier 1 supplier. Haike has 15 employees, most of whom have Ph.D. degrees and came from senior level engineering positions at other automotive firms. Including Dr. Liao, four of their employees are both qianren and sea turtles.

Dr. Liao chose to headquarter Haike in Changzhou due to its favorable environment for technology startups, including free office space and reduced rent on pilot production facilities as part of the “Changzhou NEV Research Academy.” One of Haike’s senior managers said, “When I first went to Changzhou, I noted the strange level of support at the full levels [of government]—high-level, the mayor, etc.—and how interested they seemed to be in what we were doing...each city retains...”

5.2.2. Haike technologies: 大巧若拙, 大道至简 (dumbing down is the way up)

Haike Technologies is an example of a firm experimenting at the subsystem and component levels of the PEV technology platform. Founded in 2012 and based in Changzhou, Jiangsu Province, Haike is commercializing a hybrid transmission that uses a mechanical flywheel to recover energy losses during vehicle braking and reduce the battery performance requirements for BEVs, with the ultimate goal of improving vehicle performance at reduced cost.

Unlike traditional hybrid systems that recover energy from braking by charging a battery, the flywheel system stores kinetic energy by spinning a disc to very high speeds. The primary advantages of flywheels over batteries for storing energy is that they avoid efficiency losses from converting between kinetic and electrical energy, and they can reduce BEV costs by reducing the power and capacity requirements of the battery pack and motor. While Haike is focused on implementing their solution for BEVs, the system could also be used to improve efficiencies in traditional gasoline vehicles similar to existing hybrid electric powertrains such as that in the Toyota Prius—a larger market of nearly 2 million hybrid vehicle sales worldwide compared to 700 thousand PEVs in 2016.

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29 Interview 47.
30 Interview 19.
31 Interview 24.
32 Official name: 常州海科新能源技术有限公司 (Changzhou Haike New Energy Tech Co., Ltd.).
33 Interviews 27 & 35.
34 Interview 27.
35 Interview 35.
something like 30 percent of all the tax revenue generated in the city, so the cities do have the freedom to back the winners they choose.”39 In addition, headquartering in China was a strategic decision to focus on China’s domestic market for hybrid transmissions since foreign competitors like Toyota and Ford (which control the patents on traditional electric hybrid drivetrains) have hesitated to bring hybrid electric technologies. Finally, engineering costs are lower in China due to lower wages for R&D engineers, and Changzhou is located in the heart of the Yangtze River Basin automotive hub with one of the world’s largest supplies of automotive engineers.37

Likewise, Haike employees emphasized the unique opportunities they have in China to develop low cost alternative hybrid transmissions due to the lack of competition by foreign competitors like Toyota and Ford, who control the patents on traditional electric hybrid drivetrains. Interviews with managers at multiple JV firms reveal that IP sharing requirements within the JV regulation, local content requirements for subsidy eligibility, and high import tariffs (25%) have all contributed to the hesitation of multinational firms to bring hybrid technologies to their JV partners in China.

For their first prototype, Haike engineers worked for one year with an alliance of Chinese suppliers to reverse engineer and locally source approximately 60 components for a planetary gearing system based on a design by Toyota. The gearing system is critical for controlling the flywheel-motor interface, and by redesigning core components and locally sourcing them Haike was able to design and build its first prototype without infringing on existing patents. In July 2012, they completed a 100km-range prototype transmission test, and in December 2012 they installed their first fully-functional prototype transmission on a BEV mid-size industrial truck that was able to achieve the same driving range using only two-thirds of its original battery pack. Since 2015, they installed an improved prototype in two other pilot vehicles: a Beijing Motor all-electric sports car and a Great Wall K50 sports car. Results showed a 50% reduction in the overall drivetrain cost, a 50–80% improvement in acceleration performance, and a 30–50% improvement in energy savings.

In summary, Haike’s strategy was to address demand for hybrid transmissions with higher energy-efficiency and lower cost than conventional hybrid electric drive trains not yet available on the Chinese market and also protected by strong patent thickets. Haike is adapted to an existing high-tech, niche (formula racing) product for low-cost mass production, and tapped into many local resources, including city-level facilities (and a wealth of experienced, low-cost R&D engineers). Dr. Liao referred to Haike’s commercialization strategy of simplifying the technology to meet China’s market needs with the Chinese idiom “大巧若拙, 大道至简” (dà qiǎo ruò zhuō, dà dào zhì jiǎn), which literally means, “intelligent people can often seem slow-witted”; Dr. Liao translated the phrase as “dumbing down is the way up.”38

5.2.3. Jiayuan electric vehicles39

Jiayuan Electric Vehicles is an example of a firm experimenting at the core system and subsystem levels of the PEV technology platform. By combining decades of experience in electric motor and controller design with a localized vehicle production system, Jiayuan is entering the rapidly growing low-speed EV (LSEV) market.

Jiayuan was founded in 1990 and is based in Nanjing, Jiangsu Province. One of the oldest PEV firms in China, Jiayuan’s origins go back to the late 1970s and early 1980s when the co-founder, Professor Li of Zhengzhou University, began conducting R&D on electronic motors and controllers. A professor of physics, Professor Li was awarded several research grants in the late 1970s to research electric vehicle technology. In 1985, he established China Electric Vehicle Society in Henan Province, and in 1989 he became the first director of the Electric Vehicle R&D Institute, which was in charge of overseeing national electric vehicle technology development. Professor Li wrote China’s earliest policy recommendations on establishing technical standards for electric vehicles in the 8th five-year plan (1991–1995).

In 1990, Professor Li and his son who studied automotive design and engineering in college founded Zhengzhou Jiayuan Technology Co., Ltd. Their original plan was to supply China’s automakers with BEV motors and controllers Professor Li had developed. However, since China’s automobile industry was still in its infancy, they were unable to find automakers developing PEVs. As a result, they designed their own research vehicles to continue R&D on BEV component technologies. Their first BEV in 1993, which used an asynchronous motor and lead-acid batteries, had a 90-mile range, which is comparable to GM’s EV1 that came out three years later in 1996. In 2001, Jiayuan completed a BEV conversion of a conventional Xiali sedan with a range of 276 miles and a top speed of 60 mph using a lithium cobalt oxide battery pack.40

That same year, Chinese policy makers established China’s first national standards for BEVs (75 mph minimum top speed, 125-mile minimum range, and usage of lithium ion batteries), which at the time no automakers had achieved. In addition to these restrictions, obtaining an automobile manufacturing license from the central government to domestically sell vehicles required proof of billions of RMB in investment and the ability to produce conventional gasoline vehicles. Unable to meet these requirements, Jiayuan was limited to exporting their BEVs to Europe. During this period, Jiayuan developed a number of different BEVs, ranging from small sedans and SUVs (mostly as research vehicles) to mini buses and electric sightseeing buses for tourism. Exporting these small projects provided enough revenue to continue a small R&D effort, but without a license they were unable to expand their company.41

In 2006–2007, low-speed vehicle manufacturers began producing low-speed electric vehicles (LSEVs) as low-cost vehicles for China’s rural countryside. Shifeng Group, founded in 1993 as a producer of low-speed, three-wheeled diesel trucks, began producing LSEVs in 2007. Their sales have grown from 10,000 in 2009 to 60,000 by 2014, and their annual production reached 100,000 units in 2015. The rural countryside of Shandong Province is home to an estimated 22 LSEV manufacturers (including Shifeng) that comprised approximately 60% of the 300,000 LSEVs sold in China in 2014, generating an estimated RMB 6.5 billion ($1.1 billion) in revenue.42 LSEVs do not fall into any particular regulatory category, and because supply chains, factories, and workers are localized, many local governments have allowed LSEV manufacturers to produce and sell their vehicles with little to no regulatory oversight. Reflecting on the emergence of LSEVs, one senior engineer at Shanghai Automotive (China’s largest automaker and JV partner with GM and VW) said, “存在就是合理的” (cún zài jiù shì hěn de), meaning “if it exists, then it must be reasonable.”43 In this regulatory gray area, Jiayuan has found an

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36 Interview 35.
37 Interview 52.
38 Interview 27.
39 Official name: 南京嘉远特种电动车制造有限公司 (Nanjing Jiayuan Special Electric Vehicles Manufacturing Co., Ltd.).
41 Interview 33.
44 Interview 30. The Chinese phrase cun zai jiu shi heni de can also be translated as “what is rational is real, and what is real is rational.”
opportunity to expand and domestically sell electric vehicles. While many of the Shandong manufacturers are marketing LSEVs towards rural households, Jiayuan is marketing their LSEV towards younger, urban consumers by adding amenities like air conditioning, navigation, and mobile phone connectivity, and they use a steel rather than fiberglass chassis for improved safety and reliability.

While Jiayuan has technical and aesthetic vehicle design capabilities, they lack mass production capabilities and investment funding. To overcome these challenges, Jiayuan has relied on localized investment and government support to gradually develop what they internally (and others externally) call a “McDonalds model.”

Rather than building few, large capacity production plants, Jiayuan is establishing many small capacity, localized production plants. With this model, local investors own the entire production facility and earn a return on all LSEVs sold from that plant. With a RMB 20 million ($3.1 million) investment, Jiayuan can establish a local plant with an annual capacity of 10,000 LSEVs. While such low production capacities and initial investments are unheard of in the traditional automotive industry, the relative simplicity of LSEVs makes economic sense at low production volumes.

In synergy with their localized investment strategy, Jiayuan has benefited from many favorable policies from local governments that are happy to provide support in the name of local economic development and the buildout of “green” products. For example, the local government in Chuzhou in Anhui Province provided a refurbished factory free of charge minus small repair costs, and local investors have provided approximately RMB 200 million ($29 million) in funding. The city of Puyang in Henan Province also provided support for land and factory costs and is also providing a RMB 7000 (~$1000) subsidy for each LSEV sold. Jiayuan’s CEO claimed, “When I call other places and say I want to build a factory there, they ask, ‘What sorts of favorable policies have local governments given you at other locations? We’ll give you the same, and then we’ll add more.’” Research has reported similar localized support for Shifeng Group, which contributes 76% of all taxes in its local county (Wang and Kimble, 2012). Jiayuan is currently working with provincial governments in Gansu, Guanxi, and Hubei, and city governments in Xingtai, Shijiazhuang, and Tangshan to establish new factories.

One challenge of a low-volume franchise production model is the lack of standardized, quality LSEV parts suppliers due to sourcing from different locations. Many LSEV manufacturers have grown out of 2- and 3-wheeled vehicle manufacturers, but component performance requirements and quality control from suppliers in these sectors are relatively low. Discussing component sourcing, a manager at Jiayuan said, “From the beginning, about 90% of our problems were with the supply chain. The failure rates for car parts need to be only a few bad parts out of a million, but in this industry it’s in the tens of percents!”

The lack of regulatory oversight may at the same time be creating barriers to establishing standards for LSEVs. Professor Ouyang Minggao, Director of Tsinghua University’s New Energy Vehicle Center, suggested as a starting point adhering to a principle of “三的三” (Three 3’s): 三米一下，三人以下，三万以下 (Less than 3 m long, less than 3 passengers, and a price less than RMB 30,000). Notably, such standards say nothing about quality, performance, or safety. In addition, the lack of quality suppliers has made it difficult to standardize or modularize components which could improve quality and safety across the industry.

The many uncertainties about the future of China’s LSEV industry challenge investor confidence. In September 2015 Jiayuan began selling the Lingzu, a 4-wheeled two-seater with a top speed of 50 km/h (31 mph) and a driving range of 150 km (93 miles). To prepare for the risk of no domestic sales, it was intentionally designed to be 2.2 m long to maximize how many can be fit into a standard international shipping container for export. Jiayuan has sold 10,000 Lingzu LSEVs (including exports) as of October 2016.

In summary, Jiayuan’s strategy seeks to address demand for low-cost personal mobility with greater comfort and flexibility over less expensive alternatives, such as electric two-wheelers, but at dramatically lower cost and greater convenience than conventional vehicles. The needs of this low-cost micro vehicle segment have historically not been able to be served with conventional internal combustion engine technologies (with perhaps the exception of India’s Tata Nano). Jiayuan combined its decades-long experience in vehicle, motor, and controller design with a localized, “McDonalds model” production system that has benefited from free or subsidized production facilities provided by local governments to serve local markets. In addition, local governments are allowing LSEV makers like Jiayuan to operate in a regulatory gray area where LSEVs can be manufactured, sold, and operated on local roads without requiring consumers to have a driver’s license or a license plate. This lack of regulatory engagement at the city and, in some cases, provincial (e.g. Shandong) level is facilitating the rapid adoption of LSEVs.

5.2.4. Kandi Technologies:

Kandi Technologies is an example of a firm experimenting at the infrastructure and core system levels of the PEV technology platform. By providing BEV charging infrastructure and modifying its business model from manufacturing and selling vehicles to manufacturing and renting BEVs, Kandi has entered China’s PEV market by operating a car sharing service that it supplies with its own BEVs.

Founded by chairman and CEO Xiaoming Hu in 2002 in Jinhua City, Zhejiang Province, Kandi was originally a producer of gasoline-powered go karts. Their first products were exclusively exported to the U.S., and by 2007 Kandi had become China’s largest exporter of high-end gasoline-powered go karts. Throughout its history, Kandi has undergone several transitions towards becoming an electric vehicle manufacturer that have coincided with local and national electric vehicle and battery R&D projects. In 1999, the Zhejiang Provincial government established the Zhejiang Electric Car Project Working Group which in 2002 became the Zhejiang WANTXIANG Electric Vehicle Development Center, a state-level center funded by the 863 National High-Tech R&D program. From October 2003 to April 2005, Mr. Hu served as the center’s general manager, and in 2006 he led the first of four projects to assess the viability of using (footnote continued) into-chinas-low-speed-electric-vehicle-revolution/

51 Interview 53.
52 The Lingzu LSEVs exported to Europe have a speed of 75 km/h (46 mph).
53 Interview 33.
54 Official name: 康迪科技公司 (Kandi Technologies Group, Inc.).
BEVs in a Hangzhou demonstration program. The project concluded that the city should invest in battery exchange infrastructure that can rapidly refuel BEVs by swapping depleted vehicle battery packs for freshly-charged packs. The battery swap system was preferred over traditional charging infrastructure, which requires dedicated parking spots and long charging times. In the same year, Kandi gained formal approval as a “Special Vehicle Manufacturer” by the National Development and Reform Commission after demonstrating Mr. Hu's patented side-loading battery swap technology in the Kandi KD5010, a two-seater BEV designed to operate with the battery exchange infrastructure.

In 2010, Kandi first piloted battery swapping with its KD5010 in nearby Jinhua through a joint agreement with the Jinhua Municipal Government and the provincial branch of State Grid, China’s largest and state-owned power provider. Construction on the first Jinhua battery charging and swapping stations began in July 2010, and by September 2010 Kandi formalized the cooperation by establishing a joint venture with State Grid and Tianeng Power, one of China’s largest battery manufacturers. Kandi’s first public vehicle sales began in late November 2010. That same year Kandi also delivered 60 BEVs to the Hangzhou Postal Service and released an improved BEV, the KD5011, which uses lithium ion batteries with a 250 km (155 mile) driving range.

These early sales were “naked” BEVs, meaning they were sold without a battery and used the battery exchange infrastructure to refuel. They were also heavily subsidized. The Jinhua Municipal Government provided local subsidies of RMB 32,000 ($5000) for the first 500 of Kandi’s sales, bringing the price down to RMB 17,000 ($2700). In 2009, the city of Hangzhou was chosen as one of the pilot cities in the “Ten Cities, Thousand Vehicles” program, which provided subsidies of RMB 60,000 ($9400) from the central government to private PEV buyers for each local electric vehicle sold in the city.

In 2012, Kandi modified its business model from swapping batteries to swapping the entire car through a car sharing mobility service where BEVs are available for hourly rental or long-term (annual) lease. The model is similar to Hangzhou’s bicycle sharing program—the first in China and largest in the world—in which users pay by the hour to rent a bike that can be returned to any station in the network. To implement the service with limited parking space, Kandi developed towerized vehicle “vending machines” that vertically park and charge vehicles and automatically swaps them when customers need a freshly-charged vehicle. So far, Kandi has constructed just two towered garages, and the rest of the vehicles in the system are parked at large businesses or hotels throughout the city.

The city of Hangzhou ordered 20,000 Kandi BEVs to implement the electric car sharing service. The project received RMB 5.4 billion ($850 million) in funding from three sources: the Hangzhou government provided RMB 800 million yuan ($126 million) in subsidies for the purchase of the cars (without batteries), the company Lithium in The Air invested RMB 2.4 billion ($378 million) to provide the batteries, and State Grid invested RMB 2.2 billion ($347 million) to provide the local battery swapping infrastructure. After launching in the second half of 2013, the car sharing program has rapidly expanded. As of the end of 2014, Kandi delivered a total of 14,398 electric vehicles to nine cities: 9852 in Hangzhou, 686 in Shanghai, 1020 in Chengdu, 340 in Nanjing, 700 in Guangzhou, 612 in Wuhan, 388 in Changsha, 500 in Changzhou, and 300 in Rugao. Reflecting on the Hangzhou model, a former general manager of multiple automotive firms in China said, “异曲同工” (yìqǔ tónggōng), which literally translates to, “different tune, equally melodic”55; figuratively, the idiom means that different approaches can also lead to equally satisfactory results.

Today, Kandi is still modifying its business model as both a manufacturer of electric vehicles and a provider of electric mobility services. In June 2014, Kandi established a “group rent” service where a fleet of Kandi electric cars are sold to a high-rise community and shared across all 400 residents for an annual fee of RMB 9600 ($1300) each. In January 2015, Kandi directly sold 60 BEVs to the Hangzhou city police—it’s first direct vehicle sales with batteries. These fleet sales and leasing opportunities may provide other growth opportunities beyond Kandi’s city car sharing businesses. In addition, in March 2013 Kandi established a RMB 1 billion ($164 million) joint venture with Geely Auto, one of China’s largest independent domestic automakers and owner of Volvo. Kandi’s recent SEC filings show that as of the end of 2014 all vehicle manufacturing has been transferred to the joint venture, leaving Kandi’s main revenue source the sale of electric vehicle parts to the joint venture.

Nonetheless, Kandi’s dependence on subsidies to remain profitable is a potential vulnerability. In January 2016, the Ministry of Industry and Information Technology increased the requirements to qualify for subsidies so that cars must have a minimum top speed of 100 kph (62 mph), which Kandi’s current BEVs do not meet. As a result, Kandi’s sales came to a halt in the first quarter of 2016 while the central government conducted a nation-wide review of subsidy policies.

In summary, Kandi’s strategy has been to address demand by urban consumers who want the conveniences of driving a car but without the cost or inconveniences (such as obtaining a license plate and parking space) of owning one in crowded Chinese cities. Kandi has been well-positioned to build relationships with local electric power providers and regulators that have been critical for establishing their business model, such as securing access to necessary parking and charging infrastructure. Kandi has also benefited from heavy local subsidies for its BEVs and charging infrastructure.

6. Discussion

Given that the PEV industry is still developing and no “dominant design” (Utterback, 1994) has emerged, theory would argue that experimentation is critical at this early stage. We contribute new insight into institutional antecedents of this experimentation in China (Klepper, 1996; Suarez and Utterback, 1995). Past findings suggest that innovation in conventional gasoline vehicles is limited in joint ventures and their local partners (Brantid and Than, 2010; Howell, 2018; Huang, 2003; Lazonick and Li, 2012; Nam, 2011). These findings, however, do not explain why experimentation across multiple levels of the PEV technology platform is abundant in independent domestic firms but virtually nonexistent in joint ventures and their Chinese partners. Our findings contribute new insights to literatures on technology transitions in platform industries and are important to answering the longstanding question of how a nation, especially an industrializing one, can reap the economic benefits of technological innovation (Acemoglu et al., 2005; Acemoglu and Robinson, 2013; Amsden, 2001; Breznitz, 2007; Lewin et al., 2016; McGregor, 2010; State Council, 2006; Taylor, 2016).56

Like other technology platforms that have been studied—e.g. microprocessors (Gayer and Cusumano, 2002), aircraft engines (Constand, 1980), high-definition televisions (Adner, 2006), machine tools (Rosenberg, 1976), electrical power systems (Hughes, 1983)—PEVs involve a complex platform of interdependent technologies. The presence of complex interdependencies across multiple levels of the PEV

55 Elements of our findings are consistent with theories from other literatures, for instance, population ecology. For example, the phenomenon of primarily young Chinese firms entering China’s PEV market could at least be partially explained by the theory of resource-partitioning: since multinational firms are targeting the mass market with traditional gasoline-powered vehicles, when new resources become available (such as government subsidies for PEVs), smaller firms will be the most likely to target those resources (Carroll, 1985; Carroll and Swaminathan, 2000; Mezias and Mezias, 2000; Swaminathan, 2001). Likewise, the emergence of entirely new products such as LSEVs can be viewed as niche market formation that is targeted by new, specialist firms (Geroski, 2001).

56 Interview 41.
Fig. 5. General hierarchical technology platform.

Table 3
Summary of case study firm experimentation and institutions.

<table>
<thead>
<tr>
<th>Experimentation Across PEV Technology Platform</th>
<th>Chery</th>
<th>Haige</th>
<th>Jiayuan</th>
<th>Kandi</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Institutions:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core System</td>
<td>Re-designing vehicle architecture enables shared CV and BEV components along integrated production line, reducing BEV cost.</td>
<td>Re-engineering specialized flywheel energy storage transmission for mass market application to reduce BEV battery and motor performance requirements at lower cost.</td>
<td>Combining electric motor and controller expertise with localized vehicle production system enables entry into low cost LSEV market.</td>
<td>Providing charging infrastructure and modifying business model reduces BEV performance requirements and enables new refueling approaches.</td>
</tr>
<tr>
<td>Local Institutions:</td>
<td>No foreign PEV competition; design for regulation.</td>
<td>No foreign competition. Free office space, low pilot production rent.</td>
<td>Licensing delayed entry. Regulatory gray area allowing local adoption.</td>
<td>No foreign PEV competition. Infrastructure support through relationship with Hangzhou city.</td>
</tr>
<tr>
<td>Infrastructure &amp; Core System</td>
<td></td>
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</table>

technology platform suggests that the platform could evolve along multiple different pathways. In addition, the hierarchical nature of the platform suggests that individual innovations in any subsystem or component could impact the pace and direction of transition to this emerging technology platform. Fig. 5 illustrates a more general picture of the hierarchical nature of the technology platform.

Our case study firms highlight several examples of experimentation across different levels of the emerging PEV technology platform. Chery and Jiayuan are both experimenting at the core system (vehicle) level, but with different approaches. Chery is reducing individual PEV component costs by redesigning the core system architecture such that multiple components and subsystems can be shared between CVs and PEVs. Jiayuan is also focused on the core system, but rather than changing the architecture Jiayuan is using its existing capabilities in designing and manufacturing low-cost BEV components and applying a localized “McDonalds” production system to achieve very low vehicle costs required to be competitive in the LSEV market. Thus, even though these firms are experimenting at the same level (core system), they are doing so in distinctly different ways for different market segments. In contrast, Haige is experimenting at the subsystem (powertrain) and component (transmission) levels. By introducing a hybrid flywheel transmission which smooths the power demand curve for the battery system over typical drive cycles, the overall performance requirements of the motor and battery are reduced, enabling the use of less expensive and more mature motor and battery technologies to achieve similar performance. Finally, Kandi is experimenting at the infrastructure (personal transportation system) and core system (vehicle) levels by changing the vehicle ownership model. By operating a car sharing business model and providing parking and refueling infrastructure, Kandi is reducing the performance requirements on key metrics, such as driving range, enabling them to design and manufacture lower cost BEVs for their business.

In contrast to our case study firms, some global firms entering the PEV industry in markets outside of China are offering more integrated products across multiple levels of the PEV technology platform. Similar to Chery, Nissan also uses shared components across CV and PEV platforms, but Nissan also controls its own in-house battery supply (core system through component levels). Likewise, Chevrolet has developed custom platforms for its PEVs and worked with Tier 1 suppliers to co-develop key components such as motors and control systems customized for their PEVs. Perhaps the most integrated entrant is Tesla. With no prior history in the conventional automotive supply chain, Tesla offers an integrated solution across many levels of the PEV technology platform, from fast charging stations and vehicles (core system) down to electric motors (component) and battery cells (base component).

Our case study analysis suggests that this variety of experimentation across multiple levels of the PEV technology platform by primarily one type of firm (independent domestic Chinese) may be related to China’s institutional setting. Specifically, our results suggest that in China’s PEV industry 1) the national JV regulation and local content requirements, have (perhaps inadvertently) removed foreign competition while rewarding domestic firm PEV activities; and 2) local policy support for local firms, such as market protection and subsidies, have extended the incubation periods for independent domestic firm experimentation. Table 3 summarizes the links between China’s national and local institutions and the experimentation by our case study firms across the emerging PEV technology platform.

These findings reveal how China’s national and local institutions may be combining in unexpected ways to not only influence which firms engage in experimentation, but also encourage platform-wide experimentation in China’s plug-in electric vehicle industry. We refer to this phenomenon of institutions combining in unexpected ways to influence firm behavior as “institutional complementarities” and propose that it can shape how a new technology platform emerges:

**Proposition 1a.** Institutional complementarities can influence which firms choose to engage in experimentation during the early phases of an emerging technology platform.

**Proposition 1b.** Institutional complementarities can influence the extent of experimentation that occurs across an emerging technology platform.

While the variety of experimentation we observe among independent domestic Chinese firms may have been an unintentional result of idiosyncratic features of China’s institutional setting, the result may be a desirable aim in spurring platform-wide experimentation during early phases of the emerging technology platform. Existing
theory on technology platforms has highlighted the important implications of interdependencies between subsystems for technological transitions, yet much of this literature focuses on the implications for strategic management of firms (Adner, 2017; Adner and Kapoor, 2010, 2016; Gawer and Cusumano, 2002). Likewise, literature that emphasizes the potential relationships between the hierarchical nature of a technology platform and the pace technological change have focused on the abilities of firms to remain competitive during periods of technological change (Christensen, 1992a; Christensen and Rosenbloom, 1995). Less has been studied about the potential relationships between institutions and the breadth of experimentation that occurs across multiple levels of emerging technology platforms. Our observations suggest that, in addition to protecting domestic firms from foreign competition, institutional complementarities in China may be serving to incubate the experimentation of domestic firms, potentially increasing the variety of experimentation across multiple levels of the emerging PEV technology platform. Other industrializing nations could consider encouraging greater experimentation by providing regions greater autonomy in deploying local resources to incubate local players as a strategy for taking a first step from imitation to innovation in emerging industries.

**Proposition 2.** Institutions that serve to incubate firms within their effective boundary in the early phases of an emerging technology platform can encourage greater platform-wide experimentation.

**Proposition 3.** Greater platform-wide experimentation in the early phases of a developing technology platform can enable it to emerge.

While early experimentation may be important, transitioning to a new technology platform could also be delayed by challenges in integrating solutions that emerge across the platform such that a value proposition fails to materialize (Adner, 2017; Adner and Kapoor, 2016). Even after promising, integrated solutions in the emerging platform manifest, coordination efforts and standards may be required in order to implement the solutions at mass scale (Iversen, 2017). For example, past research suggests that, in addition to government promotion of regional clustering in early phases, the eventual establishment of national standards was critical for the growth and maturation of the electric bike industry in China (Ruan et al., 2014). Thus, while experimentation may be important early-on, integration may be important at latter stages of new technology platform emergence. Researchers have also argued that eventually exposing firms to global competition is important for sustaining a strong national innovation system in the long term (Amsden and Chu, 2003; Nelson, 1993). Similar arguments have been made specifically in the context of technology catch-up (Brandt and Thun, 2010) and the need to transition from regional to national markets in China (Meyer, 2008). In some cases, the challenges to expanding beyond China’s protected regional economies has led firms to strategically enter foreign markets before expanding domestically in pursuit of more efficient institutions (Boisot and Meyer, 2008). It is thus unclear if the current protection from JV firms and local policy support in the PEV industry will harm independent domestic firms in the longer term by preventing them from gaining exposure to foreign competition or incentives to compete in the global marketplace.

**Proposition 4.** After a new technology platform emerges, continued institutional protection from competitive pressure can hinder maturation and scaling beyond early markets.

One pathway towards greater national market integration may be to facilitate standardization at the national level, similar to the cases of wind and solar energy (Lewis and Wiser, 2007), but this approach must be weighed against the potential to prematurely limit promising innovations. For example, research has shown that mandating the use of specific technologies (perhaps as an effort to standardize an industry) can constrain innovation and even destroy important markets for the development and adoption of new technologies (Dudek et al., 1992; Jaffe and Stavins, 1995; La Pierre, 1976; Stewart, 1991). If such local laboratories for experimentation as found in this paper indeed prove fruitful, further work needs to be done in identifying pathways for transitioning from local experimentation to national integration.

We theorize that policies should be aligned to match the dynamics of technology transitions from an incumbent to an emerging technology platform to support the transition at different phases. Policy support during early stages of an emerging technology platform should be directed at encouraging experimentation across many levels of the platform, as we are seeing in China’s emerging PEV technology platform. However, as different solutions to subsystem performance challenges emerge, policy support should adjust toward facilitating the integration of more promising solutions and increased competition. As the integrated solutions are adopted, policy support should again adjust toward the establishment of national and international standards across the various technology subsystems to facilitate production and adoption at mass scale. Fig. 6 illustrates this concept of transitions in policy support over time as the emerging technology platform is adopted.

7. Conclusions

Past research has suggested that the early stages of emerging industries is marked by a period of intense experimentation and diverse entry by many firms, but how to enable and encourage such experimentation (as well as when to transition towards encouraging greater
integration and standardization) is less understood. In this study, we examine the institutional and policy origins of diverse forms of experimentation by independent domestic Chinese firms across multiple levels of the emerging PEV technology platform in China.

Like many industrializing nations, China has structured its institutions and policies with the goals of enabling lagging domestic firms to catch up (and hopefully ultimately surpass) global incumbents in technological capabilities. We apply inductive, grounded theory-building techniques to capture and better understand how specific institutions and policies have led to the emergence of diverse experimentation by independent domestic Chinese firms across multiple levels of the PEV technology platform. Our vehicle sales, archival, and interview data reveal that independent domestic Chinese firms are dominating sales in China’s PEV industry. Our four in-depth case studies unpack the diversity of experimentation by these firms across multiple levels—infrastructure, core system, subsystem, and component—of the PEV technology platform. This experimentation contrasts with the near absence of PEV entry by incumbent JV firms and limited entry by Chinese JV partners.

In contrast to past research that finds national JV regulations are hindering domestic innovation in the established automotive industry, we find evidence that national institutions, in particular, the formal JV regulation and local content requirements, are creating disincentives for multinational firms to bring PEV technologies to their JV firms and potentially inhibiting the capabilities of Chinese JV partner firms to independently develop their own PEVs; independent domestic firms have capitalized on the resulting protected PEV market. In parallel, local policy support for local firms, such as additional market protection and multiple forms of subsidies, have turned regional markets into protected laboratories, extending the incubation periods for independent domestic firms to experiment across multiple levels of the emerging PEV technology platform in China. We propose the concept of “institutional complementarities” to describe how national and local institutions are combining in unexpected ways to not only influence which firms engage in experimentation, but also encourage platform-wide experimentation in an emerging technology platform.

While we focus on the specific institutional setting in China and the context of transitioning from convention to plug-in electric vehicles, other factors may also affect the trends we observe. For example, China has a large, heterogeneous automotive market, and the extent to which multiple firms can experiment in different ways across a technology platform may be limited by the size of the market and the heterogeneity of demand. For example, even though the United States also has a large domestic automobile market, the personal mobility needs and available transportation infrastructure are still more homogeneous compared to those in China. In contrast, Taiwan has similarly heterogeneous mobility needs to those in China but a much smaller market size. In both the U.S. and Taiwan, we would expect more uniform experimentation across the PEV technology platform, albeit for different reasons. In addition, technology platforms in other industries may have fewer interdependencies, and thus the experimentation by different firms may be more homogeneous even in the context of extended incubation periods. For these reasons, we anticipate our theory to be more applicable in nations with large, heterogeneous domestic markets and in industries with greater levels of interdependencies across the technology platform.

While China’s market and institutional environment may have (perhaps even unintentionally) enabled independent domestic Chinese firms to capture the majority of the emerging PEV market, continuing in this direction could undermine extended domestic and even international growth (Barwick et al., 2016). Researchers have argued for the need to transition from regional to national markets in China (Boisot and Meyer, 2008; Meyer, 2008; Wei et al., 2017). A lack of functional national charging standards, for example, could inhibit the ability of firms to expand to other domestic markets, and the lack of exposure to foreign competition could inhibit their expansion into international markets. Future research should identify pathways for making the transition from regional experimentation to national integration. Recognizing the important role that institutions can inadvertently play in shaping the decisions of would-be innovators has implications for industrial policy design. It can also shed light on conditions that could enable (or inhibit) large-scale technology transitions led by new or unexpected players from the developing world.

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Appendix A. Supplementary data

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